Cognitive performance in chronic tinnitus patients : a cross-sectional study using the RBANS-H

1. Abstract

Objective: Many tinnitus patients report cognitive deficits such as concentration and attention difficulties. The aim of this study was to comprehensively assess cognitive functioning in tinnitus patients using a standardized test battery, the Repeatable Battery for the Assessment of Neuropsychological Status adjusted for Hearing impaired individuals (RBANS-H).

Study design: Cross-sectional study

Setting: Tertiary referral center

Participants: Twenty-eight chronic tinnitus patients and twenty-eight control participants, matched for gender, age, hearing loss, and education level

Intervention: Diagnostic

Main outcome measures: All participants completed the RBANS-H, which includes subtests probing immediate and delayed memory, visuospatial capabilities, language, and attention. The tinnitus patients completed the Tinnitus Functional Index (TFI), a Visual Analogue Scale (VAS) measuring subjective mean tinnitus loudness and the Hyperacusis Questionnaire (HQ).

Results: The total RBANS-H scores did not differ between tinnitus patients and controls. However, on the language subscale, mean scores of the tinnitus group (97.6 ± 11.0) were significantly lower than those of controls (104.4 ± 12.0), with correction for gender, age, hearing level, and education level (general linear model: p = .034). *Post hoc* t-tests revealed a specific deficit concerning the semantic fluency subtest (tinnitus: 19.5 ± 6.2; control: 23.1 ± 5.9; p = .015). No correlations between TFI and RBANS-H scores were found, while VAS scores for tinnitus loudness were negatively correlated to scores on the RBANS-H attention subscale (r = -.48, p = .012).

Conclusions: The current study successfully employed the RBANS-H to provide a broader view on cognitive functioning in tinnitus patients. The results showed a specific negative influence of tinnitus on verbal fluency, which could be related to a deficit in executive cognitive control. Moreover, patients experiencing louder tinnitus performed worse on specific subtests concerning attention.

Keywords: cognition, tinnitus, RBANS-H

2. Introduction

Tinnitus, defined as the perception of sound in the absence of a corresponding external sound source, has a worldwide prevalence of 10-20% (1,2). For a subset of patients amounting to 2-4% of the population, chronic tinnitus holds a significant burden on the quality of life, affecting diverse domains such as sleep quality and social interaction (3,4). Many tinnitus patients report increased stress levels and psychological distress, such as feelings of anxiety or depression (5,6). Next to this well-documented psychological burden, tinnitus patients often report cognitive deficits such as concentration and attention difficulties (7-9). Chronic tinnitus is characterized by maladaptive plastic changes across a wide network of cortical areas (e.g. auditory cortex) and subcortical structures (e.g. limbic lobe), with each brain area representing a particular aspect of the tinnitus perception (10-12). It has been hypothesized that the cognitive impairments seen in tinnitus patients might reflect these brain-wide alterations in neural activity (13).

A broad range of cognitive tests has been used in an attempt to chart the cognitive profile of tinnitus patients. Results of these tests have been extensively reviewed elsewhere (14-16). Although subjective complaints of cognitive difficulties are not always reflected in objective cognitive measures, collectively, these research efforts have revealed subtle but consistent effects of tinnitus on cognition. Most authors have focused on attentional deficits in tinnitus patients, revealing that the executive control of attention is specifically impaired in tinnitus (17-19). Patients appear to score worse on specific paradigms probing selective or divided attention, presumably because they experience difficulty with the allocation of attentional resources. Performance on selective attention tests, such as the widely used Stroop paradigm, is correlated with tinnitus severity as probed by specific questionnaires (20,21).

Effects of tinnitus on other cognitive domains can also be observed. Auditory working memory might be impaired in tinnitus patients, as they perform worse on reading span and serial recall tests (22,23). Deficits in language processing have also been reported, with tinnitus patients scoring lower than controls on the Controlled Oral Word Association Test (COWAT), a task probing verbal fluency (24). Finally, listening effort was found to be significantly higher in tinnitus patients than controls, irrespective of hearing levels (25). This finding may also point to a reduced cognitive capacity in tinnitus patients.

Some authors have employed general cognitive screening tools, more specifically the Mini-Mental State Examination (MMSE), in an attempt to assess overall cognition in tinnitus patients (26-28). Using these screening tests, only minor and mostly non-significant differences between tinnitus patients and controls have been found. However, it must be noted that tools such as the MMSE have been explicitly designed to rapidly screen for dementia and might not be comprehensive enough to unearth fundamental effects of tinnitus on cognition.

Overall, highly specific aspects of cognition have been tested in different subpopulations of tinnitus patients. The use of a global comprehensive test battery in a population of tinnitus patients and controls would greatly benefit the understanding of the effect of tinnitus on general cognition. In this study, we used the Repeatable Battery for the Assessment of Neuropsychological Status for Hearing impaired individuals (RBANS-H) (29) to assess the effects of tinnitus on different cognitive domains. The RBANS-H is a comprehensive cognitive test battery, assessing different facets of cognition including memory, attention, visuospatial capabilities and language processing (29-32). The oral instructions and auditory stimuli of the RBANS are supported by written explanations and visual stimuli in the RBANS-H, which makes the RBANS-H usable for assessing patients with hearing loss. Another major advantage is that this test yields one total score of cognition, which is convertible to an age-corrected standard score with a mean of 100 and a standard deviation of 15. This score is not susceptible to floor or ceiling effects, both in healthy and diseased older populations (33). Finally, the administration time is short (approximately 20 to 30 min), hence the RBANS-H is suitable for clinical settings.

This study aims to investigate the effect of chronic tinnitus on different aspects of global cognition. To this end, we compared performance on the RBANS-H between tinnitus patients and controls. Furthermore, as subjects suffering from highly intrusive tinnitus were expected to perform worse on the cognitive test, we investigated the association between subjective tinnitus characteristics and RBANS-H performance.

3. Materials and Methods

3.1 Subjects

A total of 28 chronic (> six months) tinnitus patients and 28 control subjects (matched for gender, age, hearing level and education level) participated in the current cross-sectional study. Tinnitus patients from the Otorhinolaryngology, Head and Neck Surgery department of the Antwerp University Hospital (UZA) were invited to participate. Control subjects were recruited by advertising. Self-reported tinnitus was considered as an exclusion criterion for the control group. The demographic details are summarised in table 1.

3.2 Study design

The current study was a cross-sectional, prospective study. The examination consisted of a cognitive assessment, followed by audiological measurements. In addition, the tinnitus perception of the patients was investigated by means of tinnitus questionnaires. The complete assessment was conducted in one appointment, which took on average two hours.

3.2.1 Cognitive assessment

The cognitive function of all participants was assessed by means of the RBANS-H (29,30), which is a neuropsychological test battery for examining cognitive function in hearing-impaired individuals. The RBANS-H provides written instructions and visual stimuli, presented on a PowerPoint presentation, combined with the standard oral instructions and auditory stimuli of the RBANS (30). The cognition scores of this test can be converted to age-corrected scores with a mean of 100 and a standard deviation of 15. Moreover, it comprises 12 subtests, which assess five cognitive domains. *Immediate memory*, the first domain, consists of the subtests List learning and Story memory. The *Visuospatial/constructional* domain is assessed by use of a Figure copy and Line orientation task. The third domain, *Language*, comprises Picture naming and Semantic fluency. The Digit span and Coding task are conducted to assess *Attention*. The last domain, *Delayed memory*, includes List recall, List recognition, Story recall and Figure recall. Finally, the RBANS-H is able to differentiate between different levels of normal cognition, which is in contrast with other cognitive screening tools (30).

3.2.2 Audiological measurements

The results of the audiological measurements are presented in figure 1. First, pure tone audiometry for air conduction was performed at 125, 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz using a 2-channel Interacoustics AC-40 audiometer and headphones in a sound treated booth, according to current clinical standards (ISO 8253-1, 2010). Second, speech recognition in quiet was measured using the NVA, which is developed by the Nederlandse Vereniging voor Audiologie (NVA) (34,35). The NVA uses Dutch open-set lists, with each list containing 12 monosyllabic words (consonant-vowel-consonant) and the first word being a training item. The loudness at which the participant reached 50% speech recognition was calculated (i.e. the speech-reception threshold (SRT)).

3.2.3 Tinnitus questionnaires

All patients filled out the Tinnitus Functional Index (TFI) (36,37), which is a self-report questionnaire consisting of 25 questions measuring the negative impact and severity of the tinnitus. The subject must answer each question on a Likert scale from 0 to 10. The total score ranges from 0-100, with higher scores indicating higher levels of disturbance (36,37).

A visual analogue scale (VAS) was used to determine the mean subjective tinnitus loudness. Patients scored this loudness with the help of a ruler between 0 and 100, where 0 means ‘no audible tinnitus’ and 100 indicates ‘extremely loud’ (38). If the tinnitus was bilateral, the maximum score of both ears was taken into account in the statistical analysis.

In many patients, tinnitus is associated with psychiatric disorders such as anxiety and depression. We screened for the presence of these comorbidities using the Hospital Anxiety and Depression Scale

(39,40). This screening tool consists of 14 questions, of which 7 relate to anxiety and 7 to depression. A score of 11 or higher on either subscale indicates clinically elevated anxiety or depression levels.

Lastly, as tinnitus is often accompanied by increased sensitivity to sound, hyperacusis was assessed using the Hyperacusis Questionnaire (HQ) (41). The HQ consists of 14 questions that probe the subject's hypersensitivity to sound, with a total score of higher than 28 indicating the presence of hyperacusis.

3.3 Statistical analysis

The objectives of the current study were (1) to evaluate the cognition of the tinnitus patients in comparison with the control subjects and (2) to determine whether the cognition was correlated with the tinnitus characteristics.

The Shapiro-Wilk test was performed to evaluate the normal distribution of the data. In addition, the normality was determined by visualising the data in histograms. The normality of the reported data was confirmed. Therefore, parametric tests with mean and standard deviation of the variables are reported.

In order to fulfil the first objective, mean RBANS-H scores of tinnitus patients and controls were compared in a univariate analysis of variance. Covariates were added to the general linear model in a forward stepwise manner. For the second objective, associations between different variables within the data were explored by performing Pearson correlations. Then, linear models with forward selection were conducted to control for other influencing factors. The significance level was set at $p < .05$.

3.4 Ethics statement

The Committee for Medical Ethics of the University Hospital Antwerp approved the study (file number: 17/18/228). All participants gave written informed consent prior to testing.

4. Results

4.1 Cognitive performance of tinnitus patients

RBANS-H total scores did not differ between tinnitus patients and controls (mean ± SD in tinnitus group: 100.0 ± 14.1; control group: 103.6 ± 12.8; $p = .33$). Scores on all subscales were compared between groups. Only scores on the *Language* subscale differed significantly, with tinnitus patients scoring lower than controls (mean ± SD in tinnitus group: 97.6 ± 11.0; control group: 104.4 ± 12.0; $p = .034$) (Figure 2). Next to this effect of group, a significant effect of gender on the RBANS-H *Language* score was identified, with women scoring higher than men ($F(1,52) = 16.6$; $p < .001$). The difference in *Language* score between tinnitus patients and controls remained significant after correcting for gender differences ($F(1,52) = 22.5$; $p = .021$). No significant interaction between group and gender was found. *Post hoc* t-

tests revealed that tinnitus patients specifically performed worse on the Semantic fluency subtest (mean ± SD in tinnitus group: 19.5 ± 6.2; control group: 23.1 ± 5.9; t (54) = 2.21; p = .015).

4.2 Cognition and tinnitus characteristics

In order to explore possible relationships between tinnitus characteristics and cognitive performance, RBANS-H scores were correlated with TFI and VAS scores. No significant correlations were found between TFI scores (including subscale scores) and RBANS-H scores (including subscale scores). A negative correlation between mean VAS scores and total RBANS-H scores was identified (r = -.30, p = .13) (Figure 3). To investigate the possible effects of covariates on this correlation, a general linear model analysis was performed. A significant effect of gender on RBANS-H total score was identified, with women scoring higher than men (F (1,24) = 14,3, p = .022). The effect of the mean VAS score on total RBANS-H scores proved to be significant when correcting for gender differences (F (1,24) = 4.83, p = .005). No significant interaction between group and gender was found. Further analysis of the RBANS-H subscales exposed a specific correlation between mean VAS scores and scores on the RBANS *Attention* subscale (r = -.48, p = .012). No other RBANS-H subscale scores were correlated with VAS scores (table 2).

To investigate the possible influence of depression on cognitive performance, we screened for the presence or absence of clinical depression in our tinnitus population using the HADS. Out of 28 tinnitus patients, six scored 11 or higher on the depression subscale, indicating signs of clinical depression. HADS scores were not significantly correlated to either RBANS-H total scores or subscale scores, nor did RBANS-H scores differ between cases and non-cases, demonstrating that signs of clinical depression did not influence cognitive performance in this tinnitus population.

Lastly, possible effects of hyperacusis on cognition and tinnitus severity were assessed. Although none of the patients in the tinnitus group appointed hyperacusis as their primary complaint, 5 out of 28 patients scored higher than 28 on the HQ, which signifies the presence of hyperacusis. No significant correlations between scores on the HQ and RBANS-H, TFI or VAS scores were found, indicating that the presence or absence of hyperacusis did not affect cognition or tinnitus severity.

5. Discussion and Conclusion

The current study explored, for the first time, the effects of tinnitus on different aspects of cognition by comparing the cognitive performance on a global comprehensive test battery between tinnitus patients and controls. Moreover, the association between subjective tinnitus characteristics and objective cognitive performance was investigated.

Overall, no major cognitive deficits in tinnitus patients were found, but the subtle nature of effects of tinnitus on cognition could be confirmed. Tinnitus patients differed significantly from the control subjects on the verbal fluency task of the RBANS-H. This result is partially in agreement with earlier reported results. McKenna (24) also showed that tinnitus patients score lower on the COWAT, a task probing verbal fluency. When this task is included in a dual-task paradigm, reaction time for the other task increases in tinnitus patients, as shown by Hallam et al. (23). However, other papers do not report differences in verbal fluency between tinnitus and controls. This discrepancy could be attributed to these studies not controlling for hearing level (42) and/or expected gender differences (43).

Verbal fluency tasks are widely used to assess general verbal ability in healthy adults (e.g. Federmeier et al. (44)), but as they place considerable demand on executive functioning, these tasks can also be understood as an assessment of executive cognitive control (45-47). As we found no differences in picture naming abilities between patients and controls, it is likely that the observed deficit in semantic fluency can be interpreted as a reflection of impaired executive control in tinnitus patients. Executive processing is typically controlled by prefrontal brain structures and it has been shown that prefrontal integrity is determinative for verbal fluency performance (48). Alterations in the activity of the dorsolateral prefrontal cortex have been found in tinnitus patients (49) and this altered activity has been directly linked to executive cognitive performance (50). In this light, our finding would further confirm the established hypothesis that intrusive tinnitus impairs the allocation of attentional resources and executive control, possibly due to altered activity in the prefrontal cortex (16).

As the tinnitus population is highly heterogeneous, the question arose whether cognition was influenced by tinnitus characteristics. Indeed, subjective tinnitus loudness influenced both the overall cognitive performance and the *Attention* scores. This result suggests that, although we found no overall deficits in cognition in tinnitus patients, patients with higher subjective tinnitus loudness experience a higher burden on attentional resources. In accordance with the present results, a previous study has demonstrated that subjective tinnitus annoyance is related to the performance on attention tasks (51). Similarly, it has been shown that performance on the digit-symbol test, which is highly similar to the coding subtest of the RBANS-H, is influenced by tinnitus-related distress (52).Together with these previously published findings, our results show that subjective tinnitus intrusiveness negatively affects attention in the tinnitus population.

In the current study, TFI scores were not correlated with RBANS-H scores. The sample size of this explorative study might be too small to reliably detect correlations between TFI scores and RBANS-H scores. On the other hand, it might also be the case that tinnitus severity as measured by the TFI is not specifically correlated to objective cognitive performance. The independence of RBANS-H scores on the

cognitive subscale of the TFI could indicate that these two measurements assess different aspects of cognition. These results are in agreement with those obtained by Trevis et al. (53), who reported no correlation between objective cognitive performance and subjective assessment of cognition. Hence, there is a need for objective cognitive tests to be added to the standard subjective questionnaires.

This paper provides the first comprehensive assessment of cognition in tinnitus patients. The results confirm the importance of a global test battery in order to understand the effects of tinnitus on general cognition, contrary to other cognitive tools which may not be sufficiently discriminatory or overlook relevant cognitive domains. A larger sample size would have been beneficial to unravel the possible distortions in cognitive subdomains and the influencing tinnitus characteristics. Yet, the collection of the tinnitus characteristics resulted in interesting correlations with the cognition scores. As the tinnitus patients and control subjects were matched, the current study is able to eliminate the influence of age, gender, hearing and education. Nevertheless, these findings could have been more generalisable if the tinnitus group better reflected the tinnitus population.

In conclusion, the current results of the general cognitive test indicated a specific distortion of semantic fluency in tinnitus patients, which might be related to a deficit in executive cognitive control. The most relevant finding to emerge from the current study is that subjective tinnitus loudness is determinative for the cognitive deficits experienced by tinnitus patients, which encourage further investigation on the relevance of 'tinnitus loudness' and a valid measure for it.

6. References

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7. Figures

Figure 1: Scattergram of the hearing results of the control and tinnitus group for their best ear. Pure tone averages (PTA) of 0.5, 1, 2 and 3 kHz are represented on the y-axis and speech-reception thresholds (SRT) of word recognition in quiet are represented on the x-axis. Each number represents the corresponding number of patients.

Figure 2: Comparison of RBANS-H scores between tinnitus patients and controls. A: Boxplots representing RBANS-H total scores (left) and Language *subscale scores (right) in controls and tinnitus patients. The boxplots show the minimum, 1st quartile, median, 2nd quartile, and maximum scores. Additional cross symbols represent the mean scores.* Language *scores differ significantly between controls and tinnitus patients (p = .034). B: Boxplots representing Semantic fluency scores in controls and tinnitus patients. The boxplots show the minimum, 1st quartile, median, 2nd quartile, and maximum scores. Additional cross symbols represent the mean scores. Semantic fluency scores differ significantly between controls and tinnitus patients (p = .015). *: p < .05.*

Figure 3: Scatterplots of RBANS-H scores and the VAS mean loudness. A: Scatterplot of total RBANS-H score and VAS mean loudness in women (black) and men (grey). Separate non-significant negative correlations were found between total RBANS-H scores and VAS mean loudness scores in women (r = -.15, p = .22) and men (r = -.30, p = .09). B: Scatterplot of RBANS-H Attention *scores and mean VAS loudness. RBANS-H* Attention *scores and mean VAS loudness scores are negatively correlated (r = -.48, p = .012) (VAS, Visual Analogue Scale).*